

CONFIGURATION AERODYNAMICS

Past - Present - Future

Richard Wood, NASA LaRC
Shreekant Agrawal, MDA
Dan Bencze, NASA ARC
Bob Kulfan, BCA
Doug Wilson, BCA

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The Configuration Aerodynamics (CA) element of the High Speed Research (HSR) program is managed by a joint NASA and Industry team, referred to as the Technology Integration Development (ITD) team. This team is responsible for the development of a broad range of technologies for improved aerodynamic performance and stability and control characteristics at subsonic to supersonic flight conditions. These objectives are pursued through the aggressive use of advanced experimental test techniques and state of the art computational methods. As the HSR program matures and transitions into the next phase the objectives of the Configuration Aerodynamics ITD are being refined to address the drag reduction needs and stability and control requirements of High Speed Civil Transport (HSCT) aircraft. In addition, the experimental and computational tools are being refined and improved to meet these challenges.

The presentation will review the work performed within the Configuration Aerodynamics element in 1994 and 1995 and then discuss the plans for the 1996-1998 time period. The final portion of the presentation will review several observations of the HSR program and the design activity within Configuration Aerodynamics.



MISSION

- Advance the HSCT aerodynamic performance, stability and control, and propulsion airframe integration technologies in the flight regime outside the terminal control area.
- Maintain close continuous technology integration with other High Speed research airframe and propulsion technology elements.

The mission of the Configuration Aerodynamics (CA) Integrated Technology Development (ITD) Team has two parts; first, it is to develop and improve aerodynamic performance, stability and control and propulsion airframe integration technologies for flight conditions outside the terminal control area and second, is to maintain close continuous coordination and technology integration activities with other HSR teams. Specific teams that the CA ITD coordinates with are the Propulsion Airframe Integration Working Group, Stability and control Working Group and the Technology Integration, High Lift, Flight controls, Inlet and Nozzle ITD Teams.



ORGANIZATIONAL AND TECHNICAL DIVERSITY

THE CONFIGURATION AERODYNAMIC TEAM:

- NASA - LaRC and ARC
- Industry - Boeing and McDonnell Douglas Aerospace
 - L-M, N-G, Dynacs, Eagle, Vigyan, CSC,
 AS&M, RIACS, DEI, Microcraft, Sterling...
- Academia - Princeton, Old Dominion, George Washington

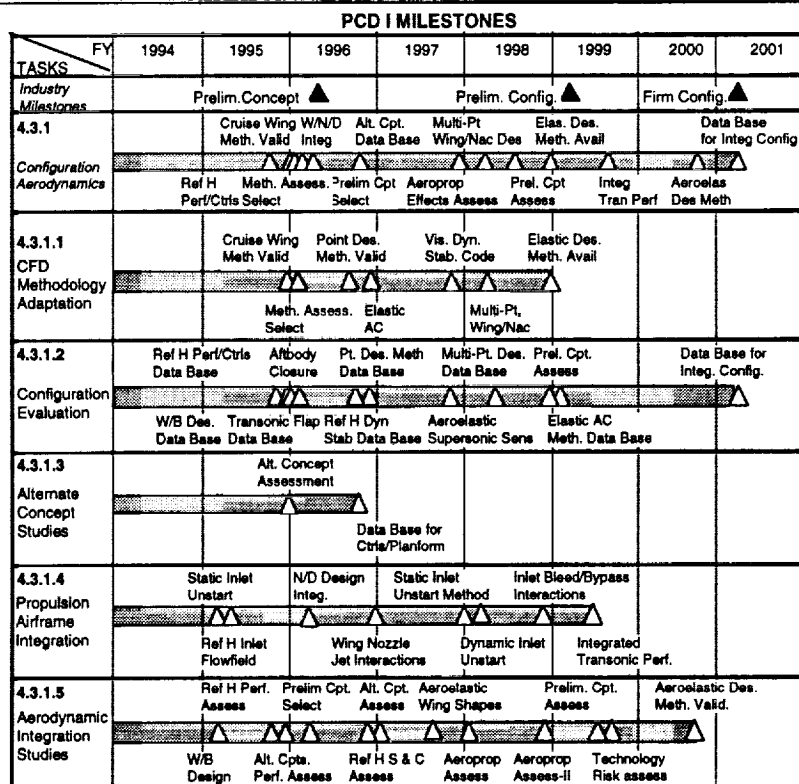
TECHNICAL RESPONSIBILITIES:

- Aerodynamic Design
- Aerodynamic Performance
- Stability and Control
- Propulsion/Airframe Integration
- Computation Fluid Dynamic Tool Development
- Experimental Fluid Dynamic Tool Development
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In support of the teams mission, the CA ITD has developed a diverse organizational technical team which is responsible for developing a broad range of technologies. The diversity of the team is critical to ensure that all possible technologies are considered within the program. As indicated above the diverse technical responsibilities requires that efficient teaming occur and that multi-use tools be employed to maximize the resources available to the team. An area of particular concern is aerodynamic design and performance improvements. This area has been and will continue to be centered around the development of drag reduction technologies and methods for design.



First NASA/Industry HSR Configuration Aerodynamics Workshop



The 1994-2001 CA program is outlined above in the milestone chart. The 1994-1995 period was managed according to the Planning and control Document(PCD) I. As shown above, the PCD I plan contained five sub-tasks and 14 milestones which were active for the PCD I period.

A major portion of the program in this time period was the assessment of the Reference H configuration which served as the program baseline for technology developments. In addition to the Reference H focus a limited amount of research was directed at Alternate concepts within sub-tasks 3 and 5. The alternate work focused on alternate control effectors for improved stability and control and planform studies for drag reduction.

94 - 95 EXPERIMENTAL RESEARCH

• # of Facilities	5
• # of Models	10
• # of Tests	30
• # of Configurations	600
• # of Data Points	300,000
• # of Enginyears	<div><div></div><div>15 LaRC</div><div>8 ARC</div><div>4 MDA</div><div>4 BCA</div><div>2 LKHD</div></div>

A significant portion of the effort in support of PCD I was an extensive experimental test program as outlined above. The CA ITD made use of 5 wind tunnel facilities; 2 at NASA Ames and 3 at NASA Langley. The test activities produced over a quarter million data points, 70% of those obtained were in support of stability and control and 30% in support of drag reduction. As with all aspects of the CA program, the success of the experimental activity relied on a diverse group of researchers from NASA Langley, NASA Ames, McDonnell Douglas, Boeing, and Lockheed which comprised 33 engineering work years.

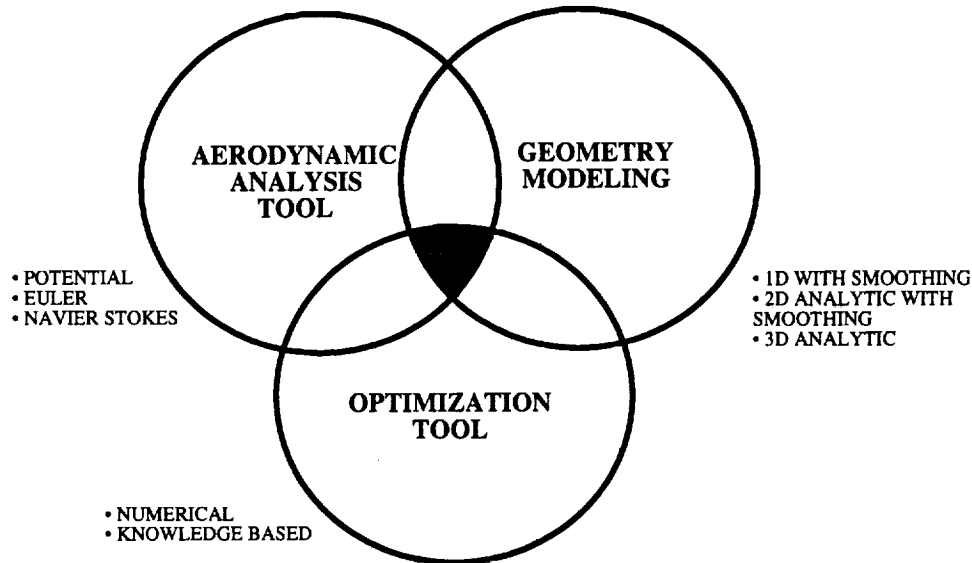
PCD I COMPUTATIONAL TOOLS

INVISCID: <ul style="list-style-type: none">• AERO2S• WINGDES• TRANAIR• AIRPLANE• CFL3D• FLO57, 67, 87• TLNS3D• USM3D	VISCOUS: <ul style="list-style-type: none">• CFL3D• GCNSfv• OVERFLOW• PAB3D• STUFF• TLNS3D
CONTRIBUTING ORGANIZATIONS: <ul style="list-style-type: none">• NASA - LaRC and ARC• Industry - Boeing and McDonnell Douglas Aerospace- L-M, N-G, Vigyan, AS&M, RIACS• Academia - Princeton	

Configuration Aerodynamics activity also utilized a wide range of computational tools for both aerodynamic analysis as well as design. Depicted above are the inviscid and viscous computational tools employed and the organizations which have contributed to the development of those tools. The inviscid methods range from the linear tools(AERO2S, WINGDES), to full potential (TRANAIR), to the Euler methods (AIRPLANE, CFL3D, etc..). The inviscid methods have served as the workhorses of the program to date due to the reduced grid generation time and computational resource costs. These methods have proven to be extremely robust and accurate for attached flow conditions, especially at supersonic speeds. The viscous methods employed within CA have also been fairly diverse in technology covering a wide range of solution methodology as well as gridding methodology. It is critical that an adequate assessment of the viscous tools be conducted because the importance of viscous analysis and design is expected to increase significantly during the next program period.

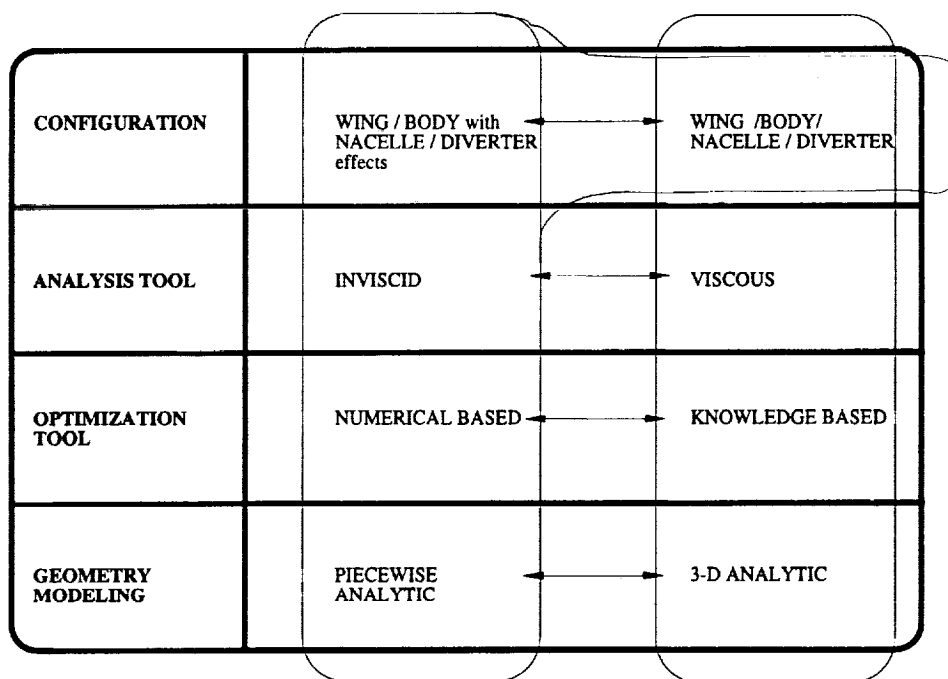
As mentioned previously, aerodynamic design is a major activity within the program. Of the methods listed above the primary aerodynamic analysis tools used in the design process are TRANAIR, FLO57-87, CFL3D(euler and Navier stokes) and OVERFLOW.

DESIGN PROCESS COMPONENTS



The aerodynamic design activities within the Configuration Aerodynamic activity have required the development of design process tools in the three areas indicated above. The areas in which design process tools are being developed are aerodynamic analysis, geometry modeling, and optimization. As previously indicated nonlinear design activities within CA have employed aerodynamic analysis tools which range from full potential to Euler to Navier-Stokes. These tools have been coupled with a variety of geometry modeling packages as indicated and have been driven by numerical optimization tools as well as knowledge driven processes. The success of the design process also requires that the above components be linked within a design concept or philosophy. The selected design philosophy will bias the selection of the aerodynamic analysis tool and the geometric model. This underlying design philosophy will be the driving force in a knowledge based design process.

PCD I AERODYNAMIC SHAPE DESIGN STUDIES



In support of the PCD I design activities the CA ITD executed three distinctly different design processes in performing four nonlinear aerodynamic cruise point shape design studies. The design processes are outlined above, as noted by the circled elements. Each design process contains four elements; the configuration under investigation, the aerodynamics analysis tool, the optimization tool, and the geometric model. As shown in the sketch the design processes used were two numerical based optimization process which utilized inviscid methods with a piecewise geometric model. The primary difference between the inviscid design processes was that one approach used the pressure field from the nacelle/diverters and the second modeled the nacelle/diverters in the design. The third process used was a viscous based design which employed a 3-D analytical geometric model and utilized a knowledge based optimization process to drive the design. As expected each of the four nonlinear aerodynamic cruise point shape design studies produced significantly different shapes yet obtained similar drag reductions from a baseline, linear-theory design.

PCD I TECHNICAL ACCOMPLISHMENTS

- Validation tests of nonlinear supersonic cruise wing/body/nacelle/diverter designs have shown up to 7cts of drag reduction.
- Experimental data show that Reynolds number and model aeroelastic effects are significant at subsonic cruise.
- Advanced experimental test techniques allow for drag measurements with 1/2 count repeatability.
- Advanced computational methods consistently compare with experimental test results within 5%. Have demonstrated cruise drag predictions within 1.5 drag counts of experimental data.

The PCD I period was successful in satisfying the objectives of the program and laying the groundwork for the PCD II period. Specific accomplishments were:

- Validation of the cruise point design processes. Test results verified a 7 count drag reduction.
- Identification of Reynolds number and aeroelastic effects at subsonic speeds.
- Development of advanced test techniques which allow drag to be measured within 1/2 count.
- Development of advanced computational methods with experimental accuracy.

PCD I MILESTONES	TECHNOLOGY CONCEPT SELECTION					
	Engine Cycle Selection	Inlet Concept Selection	Nozzle Selection	Config. Definition	Controls Selection	Aero Risk Reduction
MS-1 Design Method Adaptation						
MS-2 Analysis Method Adaptation						
MS-3 Wing/Body Design Data Base						
MS-4 Ref H Performance and Control Data Base						
MS-5 Transonic Flap Data Base						
MS-6 Afterbody Closure Assessment						
MS-7 Alternate Concept Assessment						
MS-8 Static Inlet Unstart Assessment						
MS-9 Inlet Flow Field Assessment						
MS-10 Nacelle/Diverter Design and Integration						
MS-11 Wing/Body Design						
MS-12 Ref H Aerodynamic Performance and S&C Assessment						
MS-13 Alternate Control Concepts Assessment						
MS-14 Preliminary Concepts Assessment Criteria						

In addition to the technical accomplishments listed in the previous figure the CA activity also contributed to the definition of the Technology Concept Airplane(TCA). Shown above are the 14 active milestones during the PCD I period and their relationship to 6 critical decision gates in defining the TCA. The chart shows that CA activities and the technology developed played a significant role in the TCA development process, CA technology was especially evident in defining the configuration layout and the control effectors.

PCD II MILESTONES

FY	1996	1997	1998	1999
Program Milestones	Technology Concept		Technology Concept Aerodynamic Assessment	Technology Configuration
Level II Milestones	Reference Configuration Evaluated		Optimized Aerelastic Concept	Technology Configuration Defined
Level III Milestones		Nonlinear Cruise Pt Design	Rigid Multi-Pt. Des. Method Nacelle/Diverter Integration Viscous Aeroelastic Analysis	Prop. Induced Effects Elastic Inv. Multi-Pt. Des. Aero. Design Opt. Capability
4.3.1.1 Nonlinear Rigid and Aeroelastic Analysis Method	Cruise Anal Method Select	Inv Aeroelastic Analysis Rigid Full Config F & M	Rigid Prop Induced Effects Viscous Aeroelastic Analysis	
4.3.1.2 Aerodynamic Design Optimization Capability	Def. Of OML Wing Thickness Body Shaping	Nonlinear Cruise Pt Design	Rigid Multi-Pt. Des. Method Rigid Viscous Multi-Pt. Des.	Elastic Inv. Multi-Pt. Des. Aero. Design Opt. Capability
4.3.1.3 Nacelle/Diverter Design and Airframe Integration	Assess Inlet Flow Constraints	Assess Inlet Integration	Nozzle Int. Assess	Nacelle/Diverter Integration
4.3.1.4 Technology Concept Assessment		Aerodynamic Performance	Initial Stability and Control	Prop. Induced Effects
4.3.1.99 Task Planning and Coordination	PCD 2 Inputs CA Workshop Mid Year Review	PCD 2 Updates End of Year Review Mid Year Review	PCD 2 Updates End of Year Review Mid Year Review	End of Year Review

The next phase of the HSR program will cover the time period of 1996-1998. This period will be governed by the Planning and Control Document (PCD) II and will be referred to as the PCD II period. The HSR program will redirect its focus over the next three years from the Reference H configuration to the Technology Concept Airplane. In support of this focus, the program has been rebaselined and the Configuration Aerodynamics ITD has restructured its program as indicated above. The PCD II program has been restructured into 4 technical sub-tasks and one planning sub-task. The CA program major deliverables are captured by the 8 level 3 milestones listed above. As noted in the milestones chart 6 of the 8 level 3 milestones are related to design tool development and drag reduction studies. The remaining 2 milestones support the assessment of the TCA and development of an aeroelastic analysis tool.



PCD II WBS

4.3.1.1 Nonlinear Rigid and Aeroelastic Analysis Method

- 4.3.1.1.1 Rigid Full Configuration Force and Moments
- 4.3.1.1.2 Inviscid Aeroelastic Analysis
- 4.3.1.1.3 Viscous Aeroelastic Analysis
- 4.3.1.1.4 Rigid Propulsion Induced Effects

4.3.1.2 Aerodynamic Design Optimization Capability

- 4.3.1.2.1 Nonlinear Cruise Point Design
- 4.3.1.2.2 Rigid Multi-Point Design Method Formulation
- 4.3.1.2.3 Rigid Viscous Multi-Point Design
- 4.3.1.2.4 Elastic Inviscid Multi-Point Design

4.3.1.3 Nacelle/Diverter Design and Airframe Integration

- 4.3.1.3.1 Nacelle/Diverter Integration

4.3.1.4 Technology Concept Assessment

- 4.3.1.4.1 Aerodynamic Performance
- 4.3.1.4.2 Stability and Control
- 4.3.1.4.3 Propulsion Induced Effects

4.3.1.99 Task Planning and Coordination

Depicted above is the work breakdown structure(WBS) for the CA PCD II period.



PCD II GOALS

Approach:

- To acquire a comprehensive experimental and computational aerodynamic performance, stability and control data base for the HSR Technology Concept, adapt and validate point design methods and multidisciplinary design optimization methods, design and assess alternate concepts, adapt and validate methods for multi-point aeroelastic design of airframes.

Deliverables:

- Aerodynamic data base for HSR Technology Concept.
- Validated aerodynamic analysis methods for HSCT concepts.
- Validated cruise-point and multi-point aeroelastic design methods.
- Validated aerodynamic analyses and design method for propulsion airframe integration.

The CA activity has identified drag reduction as the highest leverage technology contribution towards the development of an economically viable HSCT. Based upon this fact the program is heavily biased in this direction, as indicated above. The approach to be used in the PCD II period is similar to that in PCD I, the CA activity will rely heavily on experimental activity for design validation and for TCA assessment. The design activities will include the development of technologies for point design and multi-point design including the effects of aeroelastics.

The key deliverables during the PCD II period will be the assessment of the TCA, validation of design methods, including PAI design tools, and the development of advanced aerodynamic analysis methods which account for aeroelastic effects.



DESIGN ISSUES

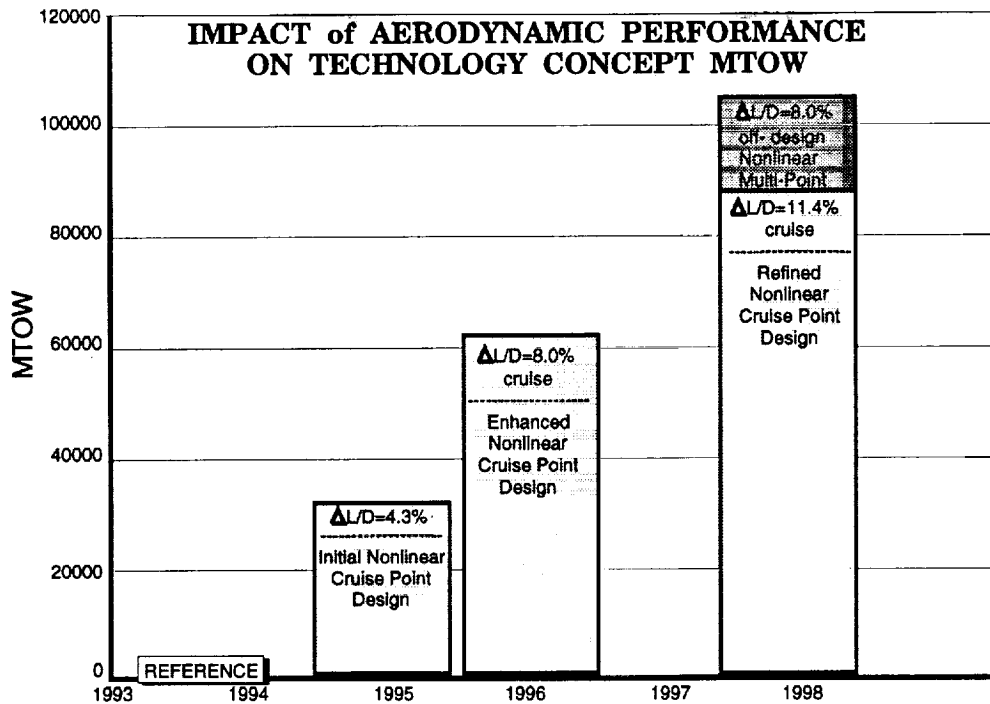
Critical Technologies

<u>Configuration</u>	<u>Test Techniques</u>	<u>Computational Methodology</u>
• Wing Shape and Volume	• Support Interference	• Efficient and Adaptive Gridding
• Fuselage Shape and Volume	• Rn Effects	• Structural Modeling
• Empennage Shape and Sizing	• Transition Fixing	• Power and Pnuematic Simulation
• Control Effector Design	• Aeroelastic Assessment	• Global/Analytic Design Variables
• Nacelle/Diverter Shape and Integration	• Foce Accounting	• Advanced Turbulence Models
• B. L. Management Techniques	• Measurement Accuracy	
	• Powered Testing	

Impact

- 15 to 18 Cts Drag Reduction from Linear Theory Design
- 87,000 to 120,000 lbs Reduction in TOGW
- Reduced Uncertainty in Transonic and Supersonic Drag Reduction
- Reduced Design Cycle Time
- Impact: Planform Selection, Payload, Vehicle Size, Engine Cycle, Inlet and Nozzle Selection

In the area of nonlinear aerodynamic shape design, there are a variety of critical configurations, experimental test techniques, and computational technologies which must be addressed if a viable design capability and thus a viable HSCT is to be developed. A listing of the most critical technologies are shown above. If the CA ITD is successful, it is expected that a 15-18 count drag reduction is achievable , from a linear theory design, which corresponds to a weight reduction up to 120,000 pounds. Another payoff to the development of these design technologies is a significant reduction in risk to Industry for product "go ahead" as well as a reduction in the design cycle time.



Shown above is a graphical display of the expected L/D improvements and resulting weight reductions associated with the point and multi-point design activities. The chart shows that a 100% improvement in the drag reduction is expected in 1996 over that achieved in 1995. And by 1998 the CA activity is expected to triple the drag reduction over the 1995 level. This level of success is critically dependent upon highly effective teamwork and a sharing of all drag reduction technologies developed within the program. The design activity is also highly dependent upon the development of advanced test techniques in the areas of aeroelastics, Reynolds number effects and transition assessment.

PCD II EXPERIMENTAL ACTIVITY

Model Number	WBS	Model	Facility	Description
1	4.3.1.2	Transonic and supersonic flow field rake	UPWT, 16'	1.7% W/B/N w pressures
2	4.3.1.2	Tech Cpt Baseline	UPWT	1.7% W/B/N w pressures
3	4.3.1.2	Tech Cpt Nonlinear Point Design	UPWT	1.7% W/B/N w pressures
4	4.3.1.2	Tech Cpt Multi Point Design	UPWT, 16'	1.7% W/B/N/Flaps w pressures
5	4.3.1.2	Tech Cpt Full Config Design	UPWT, 16'	1.7% W/B/N/Emp w pressures
6	4.3.1.2	Tech Cpt Multi-Point Design, MP 1	UPWT, 16'	1.7% W/B/N/Flaps w pressures
7	4.3.1.2	Tech Cpt Multi-Point Design, MP 3	UPWT, 16'	1.7% W/B/N w pressures
8	4.3.1.2	Tech Cpt Multi-Point Design, MP 4	UPWT, 16'	1.7% W/B/N/Flaps w pressures
9	4.3.1.2	Tech Cpt Aeroelastic, Supersonic	UPWT	1.7% W/B/N w pressures
10	4.3.1.2	Tech Cpt Aeroelastic, Transonic(shape #1)	16'	1.7% W/B/N w pressures
11	4.3.1.2	Tech Cpt Aeroelastic, Transonic(shape #1)	16'	1.7% W/B/N w pressures
12	4.3.1.3	N/D combinations (3 sets)	UPWT	Nacelle and diverters
13	4.3.1.3	Nozzle boattail drag	16'	Nozzles
14	4.3.1.3	2D Nozzles	UPWT	Nozzles
15	4.3.1.3	N/D combinations (3 sets)	UPWT	Nacelle and diverters

In support of the design activity there are a large number of wind tunnel models and test activities scheduled. These models will be used to obtain the necessary data to validate the design activities and the drag reductions obtained. Listed above are the PCD II models for support of configuration and nacelle/diverter design activities. The shaded areas correspond to models that are to be fabricated and tested in 1996. The remaining models are to be designed, fabricated, and tested in 1997 and 1998.



ANALYSIS ISSUES

Critical Technologies

Experimental Aerodynamics	Test Techniques	Analysis Methods
<ul style="list-style-type: none">• Supersonic Cruise Drag• Transonic Cruise Drag• Trim Drag• Stability and Control• Rn Effects• Power Effects	<ul style="list-style-type: none">• Support Interference• Rn Effects• Aeroelastic Measurements• Transition Modeling• Powered Models	<ul style="list-style-type: none">• Viscous Modeling• Aeroelastic Effects• Accuracy, Robustness, Efficiency• Powered Effects• Efficient Gridding

Impact

- Reduce Program Risk Due to Uncertainty in Aircraft Performance and S&C may:
 - Size the Aircraft
 - Define Cycle and Planform
 - Limit Payload and Range
- Develop Confidence in Aircraft Performance Prediction Capability
- Understand Methods and Cost for Accurate Data
- Allow Extrapolation to Flight Conditions

The second major area of work within CA for PCD II is the aerodynamic analysis/assessment of TCA. This area of work covers performance, stability and control, and propulsion effects. As with the design area, there are a number of critical technologies in experimental aerodynamics, experimental test techniques and computational analysis methods. The assessment of the TCA will rely heavily upon both advanced experimental studies as well as advanced computational activities. Several areas that will receive close scrutiny from an experimental view will be aeroelastics, boundary-layer tripping and transition, and support interference. On the computational side the program will focus on aeroelastics, turbulence modeling, and efficient gridding. The payoff to these technologies is a reduction in program risk and the improved capability of extrapolating the results to flight.



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PCD II EXPERIMENTAL ACTIVITY

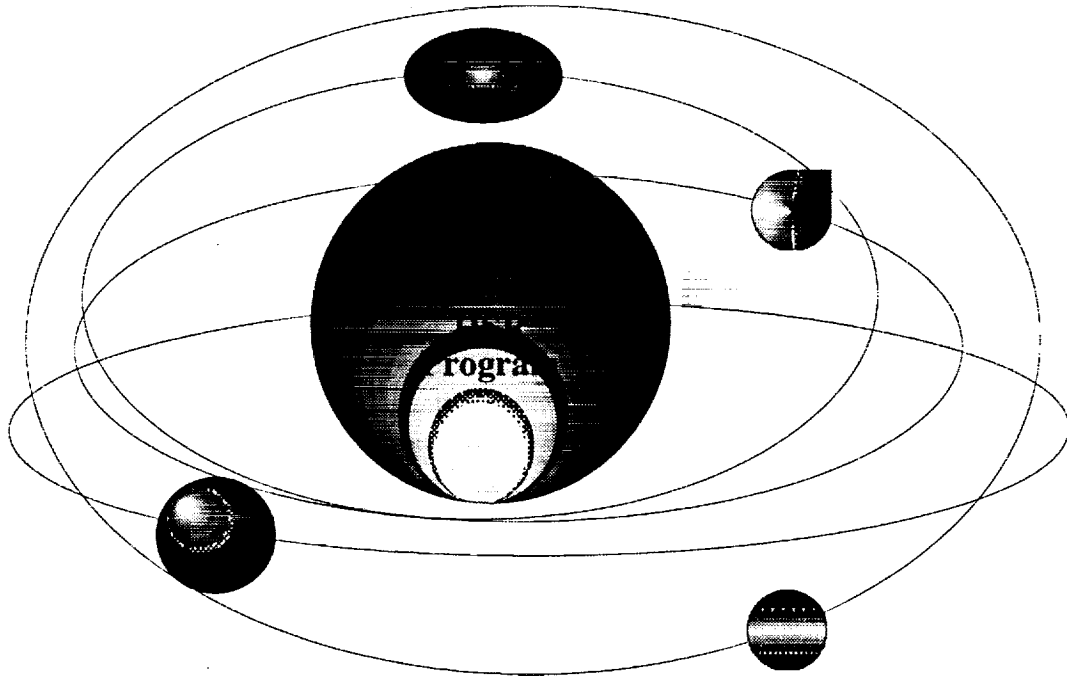
Model Number	WBS	Model	Facility	Description
16	4.3.1.4	Grit test program	UPWT, NTF	Existing model
17	4.3.1.4	Aeroelastic test program	UPWT, NTF	Existing model
19	4.3.1.4	Tech Cpt aftbody closure	UPWT, 16', NTF	1.7% W/B/N/Emp
20	4.3.1.4	High Rn performance and S&C	NTF	2.2% W/B/N/Emp
21	4.3.1.4	Tech Cpt modular	UPWT, 16'	1.7% W/B/N/Emp
22	4.3.1.4	Tech Cpt powered semi-span	11'	W/B/N/Emp
23	4.3.1.4	Tech Cpt ref semi-span	11'	W/B/N/Emp

In support of the analysis activity there are a large number of tests scheduled for the set of wind tunnel models listed above. These models will be used to obtain the necessary data to assess the TCA and provide the ground based corrections for scaling the wind tunnel data to flight conditions. The shaded areas correspond to models that are to be fabricated and tested in 1996. The remaining models are to be designed, fabricated and tested in 1997 and 1998.



OBSERVATIONS

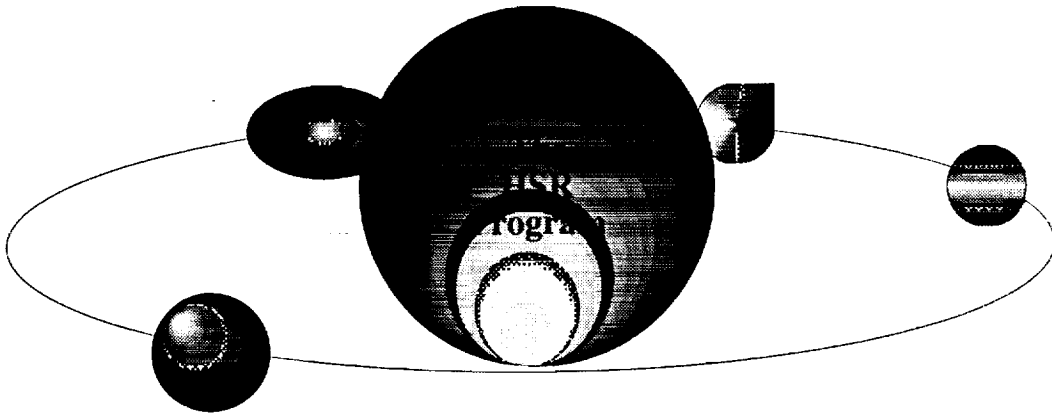
The previous figures and text discussed the details of the PCD I activity(past) and the PCD II activity (present). The following set of figures will highlight some personal observations from the past and will reflect on the needs of the HSR program now and in the future.



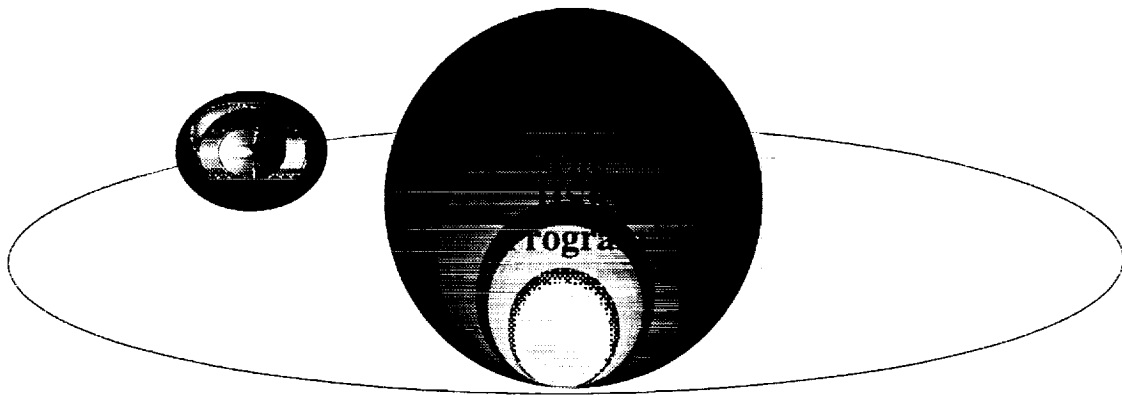
The HSR program, and especially the Configuration Aerodynamics element, has gone through significant change over the past 24 months. In 1994, the CA activity consisted of each organization operating independent of one another within the influence of the HSR program structure. As the program evolved, the CA activity had periods of alignment and misalignment from both a technical and programmatic perspective. The graphic above depicts the 1994 perspective.



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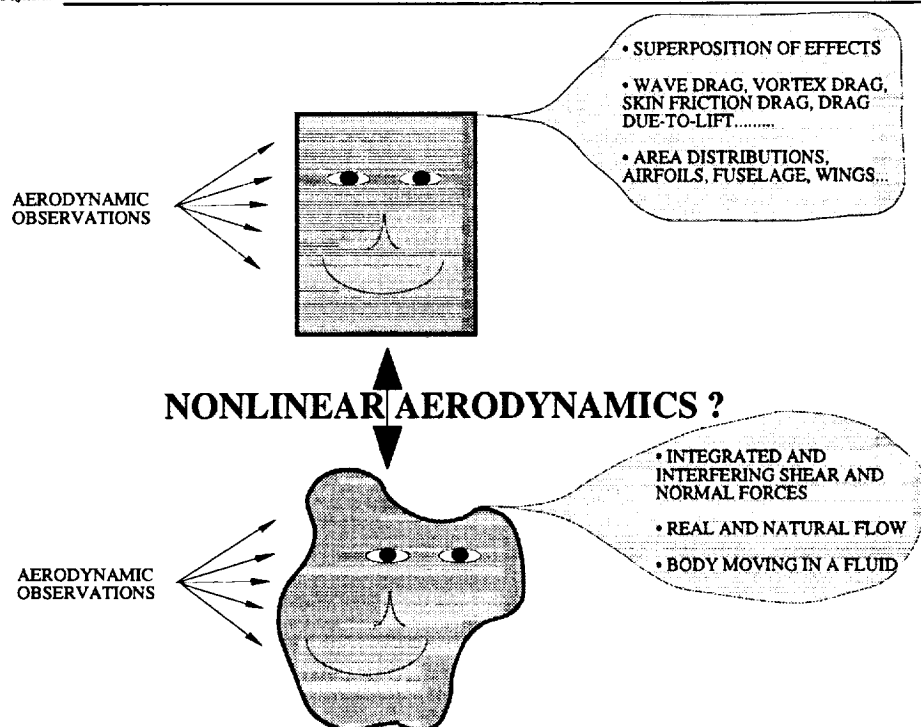
In 1995, the program adopted the PCD format, implemented team work and consensus, and began the use of schedules. These changes brought the focus of CA into alignment with the HSR program and all activities within CA centered around the HSR program. The situation had improved dramatically however it was still less than that required for program success.



The graphic shown above depicts a desirable situation for success within the program. The CA team has a single vision and operational space. This environment must maintain the characteristics of each individual organizations and must operate within the HSR program objectives and policies.

Once the programmatic aspects are achieved the CA ITD can then create a common vision for design activities. The design activity within CA is the prime focus and as such the HSR program is relying heavily on the success of CA.

However, it must be recognized that the feasible design space being investigated by CA can not be characterized by a single design approach within the HSR program but is more likely represented by a family of design approaches which are not physically connected(past). The CA ITD must assess the true character of the design space in order to find success in the drag reduction efforts.



Perhaps the most important question which must be answered is: What are nonlinear aerodynamics? And what does it mean to conduct nonlinear aerodynamic shape design. Shown above are two possible views and answers to this question. Shown on top is the traditional approach in which the explanations are provided in the standard framework and shown below is an atypical set of explanations to the same question. Each of these explanations carry with it bias errors associated with the meaning of the words and the history of the individual. However, if CA is to be successful in reducing the drag through nonlinear design then a common goal must be developed, this requires a common language. The situations of solving a linear problem with a nonlinear method or the solving a nonlinear problem with a linear method must be avoided if progress is to be made.

OBSERVATIONS

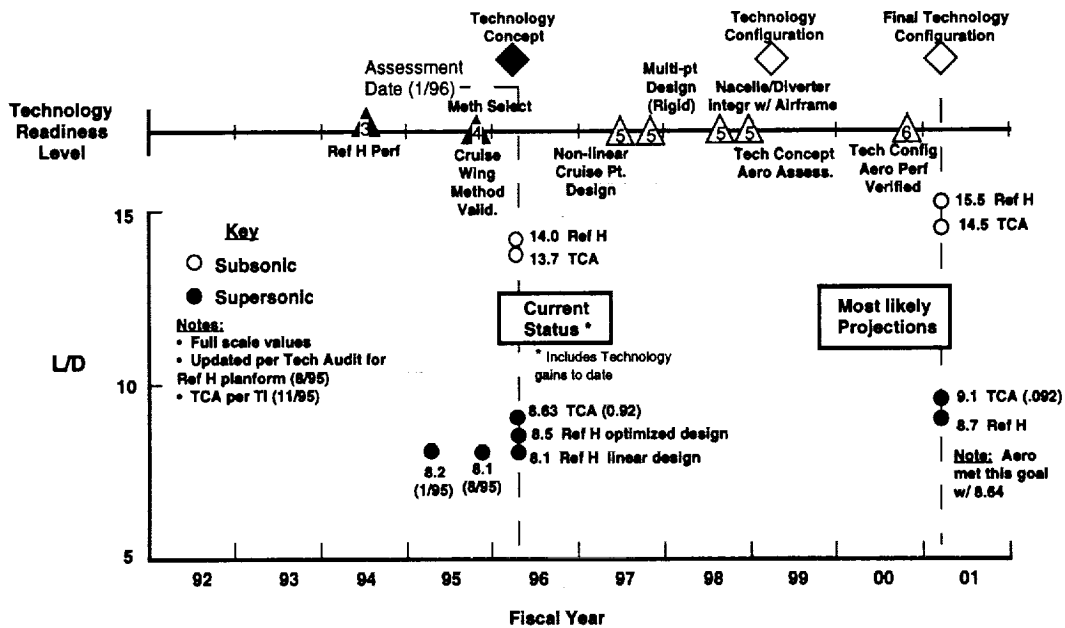
- The “REAL” nonlinear drag reduction boundaries must be identified and quantified.
 - >100% aerodynamic thrust is achievable!
 - Are Linear Theory based boundaries relative?
- Multi-Point design activity is critical to understanding the drag reduction potential of this vehicle class.
 - What design requirements are Mach number similar?
 - What performance requirements are Mach number sensitive?
- Aerodynamic technologies for S&C improvements must be pursued.
 - Control effector design opportunities exist!
 - Stability management concepts must be explored!
- Innovation and high risk work must have a home in CA.
 - Boundary layer management for performance and S&C improvements!
 - Base drag management for performance improvements!
 - Fuselage upwash management for performance and S&C improvements!
 - Vehicle volume maximization for performance improvements!

The CA element has created for itself a number of significant technical challenges that require innovative solutions and teaming to be successful. However, before progress can be made there is a need to develop a consistent set of criteria and an understanding of the opportunities available to the CA team. Listed above are several issues which should be resolved and opportunities which must be pursued.



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Technical Performance & Technology Readiness Level





TECHNOLOGY CONCEPT
CRUISE L/D_{\max} PROJECTIONS

